Biotechnology impact indicators: From measures of activities, linkages and outcomes to impact indicators

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What Indicators for Science, Technology and Innovation Policies in the 21st Century?

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by

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Introduction

A large positive rhetoric exists on future benefits of biotechnology. In short, this rhetoric could be summarized as: biotechnology is the next technology wave that will deeply transform the economy and society by providing products and processes that will solve health problems, feed the world with new agricultural products, cure the environment and provide sustainability. Beyond the rhetoric, indicators of biotechnology activity show an emerging phenomenon that is still relatively small. Many actors from the private sector, governments and universities are betting on future success of biotechnology. A recurring policy question is: what evidence provides a solid basis or argument for government to invest in biotechnology.

The last decade saw the emergence of a wealth of data and statistics attempting to portray the development of biotechnology. This work is largely summarized in the OECD Framework for Biotechnology Statistics (2005), which provide guidance and standards for the measurement of biotechnology activities. It should be noted that most of the data currently collected focuses on activities, linkages and outcomes of firms engaged in innovative activities through the use of biotechnology.

Activity indicators focuses on data collected on actors (who) performing an activity (what) in a location (where) to fulfil an objective (why). Linkage indicators collect data on how many resources were committed and how actors are connected to other social or economic organizations and institutions. Outcome indicators provide measures of results achieved. Most of these indicators are available in Canada through the wealth of surveys on the Use and Development of Biotechnology conducted by Statistics Canada.

Biotechnology specific impact indicators should measure changes induced in socio-economic indicators. Typically, an impact indicator is most of time a ratio and is tracking a change. Examples: X% of the vaccine market is composed of product developed using biotechnology compared to Y% in previous time period; X% of total R&D is made using biotechnology; occurrence of a disease, expressed as a percentage of population, diminished by Y% after the introduction of a genetic therapy...

Typical problems associated with impact indicators related to an emerging technology are twofold. When compared to long-term trends observed in major socioeconomic impact indicators, the magnitude of biotechnology related indicators appears relatively small, if not negligible. This type of impact indicators capture a net wealth effect, that is, the difference between new economic activities generated minus economic activities that were discontinued as a result of the emergence of the new technology. This paper argues that an important part of the impact of biotechnology is the result of substitution effects such as changes in productions (process innovations) and changes in supply chains. Measuring these impacts remains a challenge for statisticians.

This paper focus on impact indicators that would be relevant to policy analysts and decision makers and discuss what transformations or additions are required to existing measures of activities, linkages and outcomes to allow for the construction of impact indicators.

Overview of existing indicators and current states of international comparability

The first attempts to measure biotechnology focused on research and development activities in the late eighties Early measurement already showed rapid increases in R&D spending, almost doubling every second years (STC 199?). This was an interesting signal that biotechnology started to be adopted by businesses.

Biotechnology data collected through existing R&D surveys is usually fairly limited, providing information on numbers of actors involved, money spent and personnel involved, broken down by size, industrial sector and geographical locations. To understand better the technology adoption and innovation process associated with biotechnology requires more sophisticated data collection instruments.

Back in the late nineties, some OECD member countries' statistical office initiated their first dedicated survey of biotechnology activities in the industrial sector (re: Canada 1997, 1999, New Zealand and France). The main focus of these surveys was on the firms actively engaged in the use of biotechnology for R&D, production and, innovation purposes.

The questionnaire used to collect the information could generally be divided in three parts. The first part dealt with the determination of whether the surveyed firm was engaged in biotechnology activities and how. Typically, respondents had to indicate their use of specific biotechnologies from a list. Similar questions are used to determine the areas of application for biotechnology or innovative behaviour. Such questions allows for the building of the final population of biotechnology active firms.

The second part of questionnaire provides standard indicators of firm characteristics such as firm size, geographical location, industrial classification, ownership, firm structure and others. Determination of these characteristics requires collecting general quantitative information such as employment and revenue. Most other types are qualitative in nature and could be used to allow for segmentation of the respondent population for analysis purposes.

The third part is a mix of qualitative and quantitative information oriented towards answering specific policy and analytical questions. These questions are often similar to the questioning encountered in the measurement of innovation and described in the OECD Oslo Manual. They cover the role of alliances and partnerships, success factors and impediments, management of intellectual property instruments and, business strategies.

Because many aspects of biotechnology are related to health, food and the environment, regulation plays an important role. Regulation also creates additional lags in the innovation process. As a consequence, raising capital is an important factor to consider, both to established firms that require enough financial capital to pass through the commercialization process and, to emerging firms whom first need to survive up to the commercialization of their first products. Therefore, more emphasis is put on collecting information on raising capital in biotechnology surveys, covering attempts to raise capital, success in raising, amounts raised sources of funds and obstacles encountered.

In recognition that innovation is becoming more a collective endeavour, much attention is given on alliance and partnership formation. Two sets of reasons are generally found behind the need to enter into collaborative behaviour: management of risks and accessing capacities. Risk can be financial in nature or related to market uncertainties. For biotechnology surveys, accessing capacities include access to complementary R&D knowledge, intellectual property, production facilities, distribution networks and, regulatory management.

Concurrently to these survey developments, the OECD established an Ad Hoc Working Group on the Measurement of Biotechnology Statistics, reporting jointly to the Working Party of National Expert on Science and Technology Indicators (NESTI) and to the Working Party on Biotechnology (WPB).

The ad hoc working group met five times between 2000 and 2004 and established a statistical definition for biotechnology and proposed ways to apply the definition for R&D surveys dedicated biotechnology surveys and, patents classification. It also proposed list of potential indicators, collection guidelines, classifications schemes and, model question and model survey. This is summarized in the OECD "Framework for Biotechnology Statistics (OECD, 2005).

In 2004, the OECD hosted a workshop on the economic impacts of biotechnology. The summary record pointed out to some interesting points for the measurement of impacts. To date, most countries focused on the biotechnology activities of the dedicated firms or early adopters of the technology. However, as a transformative technology, biotechnology brings many changes to a broad spectrum of economic activities that could not be effectively monitored by focusing solely on the early adopters. Biotechnology is a tool used to develop many applications that, once developed, may have significant impacts but will not necessary be linked back to the original use of biotechnology, therefore potentially underestimating impacts of biotechnology.

A second interesting point made relates to the focus on biotechnology itself, from two different perspectives. First, biotechnology tools and applications used and developed can vary quite substantially according to application domains. There are some overlaps but also important differences in the techniques used for health, agrifood or industrial applications. Recent Canadian experience in the conducting of a bio-product survey showed that the industrial sector, outside health and agrifood, doesn't necessarily recognized itself spontaneously as being part of the biotechnology umbrella. Biotechnology can be very sector specific. Second, particularly in the industrial sector, biotechnology may only be a tool in a more fundamental process consisting of progressively substituting many existing petroleum based applications with applications based on new and different use of biomass, a renewable resource.

The measurement of biotechnology impacts will need to go beyond measurement of key activities performed by the actors directly involved in the use of technology to encompass impacts on the demand and consumer side.

Why is biotechnology important?

Biotechnology is often described as an generic and enabling technology, that is, a set of techniques that allow for a new wave of innovations (the enabling part) spread across many industries (the generic part). Nevertheless, the first key question is: how could we recognize statistically the early stages of a technology revolution? An obvious answer is through research and development activities (R&D), the early stage of innovation.

First, how important is it? In 2003, Canadian industries performed 1.5 billion (Canadian dollars) in biotechnology related R&D, This represents 12% of total industrial R&D, less than what was spent for information and communications technologies but more than aerospace ($900 million) and automobile industries ($600 million). Biotechnology R&D expenditures have experienced a two digit growth rate since 1987. However, when comparing biotechnology revenue or employment to the rest of the economy, the ratios are very, very small. If biotechnology is important, it is not yet by a tangible overall impact of the economy.

The phenomenon is clearly significant, from an R&D perspective, but how widespread is it? Biotechnology is performed within several industries, but the bulk is found is two domains: health and food applications. Biotechnology R&D is also found, but a lesser extent, in natural resources, environmental industries, informatics, and industrial applications.

Why is this so? A classic explanation could be that, still being in early stages, biotechnology activities are observed mainly in areas where applications can be developed more quickly and are entering other industrial activities more slowly. This is not entirely satisfactory since it could be noted that the regulation process required to get a product on the market impose a lag in the areas where biotechnology applications are mainly being developed. Another explanation relates to the way biotechnology is defined so far.

For statistical data collection, biotechnology is described as a set of techniques that could be used in R&D, production and for environmental applications. This way of describing biotechnology proved useful for data collection from firms directly involved with the use of biotechnology related techniques. The OECD single definition is the following:

> *The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.*

This definition should be interpreted using a list of biotechnology techniques that could be found on the OECD website (http://www.oecd.org/document/42/0,2340,en_2649_37437_1933994_1_1_1_37437,00.html).

At the heart of this definition is the use of science and technology in conjunction with material of living origin. Most of the techniques found in the OECD definition deal more with transformative processes based on the use of living material. The list tends to put aside the alterations of living material through the use of more conventional techniques. In other words, is the list currently used by the OECD countries to capture biotechnology activities potentially biased towards classical applications of biotechnology such as health and food? Answering yes to this question would imply a potential underestimation of the breadth of activities falling under the biotechnology umbrella.

To address this potential bias, Statistics Canada undertook in 2004 a first survey targeting the development of bioproducts in the industrial sector. A conclusion from this initial work was that firms engaged in more traditional economic activities may be engaged in activities that could be characterized as biotechnology but not necessarily recognized as such by the respondents. In this survey, the basic characteristic is novel use of feedstock, as an input in the development of new products and processes rather than the use of specific techniques.

Is biotechnology an important phenomenon? By the level of R&D investment, which is somehow a bet on the future, the answer is yes. But the actual impacts in terms of dispersion or changes in economic structures or activities largely remain to be measured, observed and analysed.

Discussion on potential impacts indicators

First of all, what is meant by impacts? The Statistics Canada framework (Science and Technology Activities and Impacts: A Framework for a Statistical Information System – 1998, http://www.statcan.ca/english/freepub/88-522-XIE/88-522-XIE1998001.pdf) makes a distinction between outcomes and impacts. Outcomes are direct results of a science and technology activity and impacts are those consequences for the social, economic, political and environmental system, and to science, that take longer to emerge and often more difficult to detect and impute back to their origin.

The document also make a distinction between socioeconomic impacts that are the result of the introduction of an innovation and those that affect the environment surrounding science and technology activities and result from changes in social, economic or political organization (Statcan 1998). This requires further discussion.

Innovation is a widely used term that, strictly speaking, describes the introduction on the market of a product, process and organizational innovation. It is also used to describe more widely the phenomenon of introduction, adoption and diffusion of new scientific and technological advances. Often referring to single introduction of novel products and processes, the concept of impact of innovation is a bit too narrow to describe adequately emerging and enabling technologies, a process that could be described as a stream of innovation resulting from a combination of advances in S&T and socioeconomic conditions that allow the emergence of a new technological system, that is, a system having large impacts on combinations of economic inputs (material, labour, capital and energy), on organizations, structures and institutions and, on consumer's behaviour.

Single innovation may have large impacts, the development of the internet is one example, but are better described and understood when putted back in the broad context that allowed for the emergence of such innovation, in the case of the internet, the development information and communication technologies resulting from the development of computers and communication protocols. Biotechnology is a serious candidate for being a generic and transformative technology for many reasons, one being its potential to provide and alternative to a quickly depleting resource: petroleum, through the transformation of biomass, a renewable resource.

Measurement of emerging technologies differs slightly from the measurement of innovation. The initial focus is still the firm. In innovation surveys, innovation is a characteristic of the firm who brings to the market new or significantly improved products and processes. Characteristics of innovative firms are then compared to non-innovative firms. Analysis attempt to provide an assessment of efficiency of innovative behaviours on firms overall performance, along with an assessment to whether some firm or innovation characteristics are more successful than others.

Emerging technology surveys focus on the adoption of generic technology by firms. So far, the attempt was not compare overall performance of adopters versus non-adopters but rather to provide indicators of relative penetration of emerging technologies on the market. Innovative behaviours are measured as well, but rather to make a distinction between newly adopted technologies and older, pre-existing similar technologies. For instance, the fermentation processes, strictly speaking included in biotechnologies, have been in usage in the industries for decades, if not centuries in some cases. The measurement of innovation behaviour is used in emerging technology surveys as a mean to restrict the focus on new and innovative usage of technologies.

By focusing on adoption (market penetration) rather than on innovation (firm performances), emerging and generic technologies allows for a broader assessment of the impacts of S&T changes. These impacts can be categorized along the following five categories:

- Economic (the sphere of all market transactions, including transactions on non-tangible assets)
- Social (the sphere of all social relations, including the policy environment)
- Environmental (physical environment consisting of air, water, soil, radiation, noise and other than human living organisms)
- On health (impacts on human well-being, including personal health and food supply)
- Ethical and cultural (assessment of conflict of values and cultural changes brought by emerging technologies)

So far, most of the experience gained by statistical agencies in the area of emerging technologies focused on economic impacts. There is a role to be played by national statistical agencies in the measurement of other types of impacts. But, in the case of biotechnology, not much has been attempted so far in these areas. The remaining of this paper is focussing more on economic impacts.

Economic impacts could be roughly divided in two categories: macroeconomic and microeconomic impacts. The former relates to broad economic aggregates such as productivity, economic growth, industrial structures and trade and the later focuses on price changes, transformation and substitution of inputs and, business conditions and performance. Following is a breakdown in areas of potential indicator development.

Macro-economic impacts

- Changes in productivity via innovative products and processes

Adoption of emerging technologies results in input transformation and substitution and, introduction of new products and processes that, overall, alter productivity measures. An important challenge lies in the measurement of the output, especially if part or total of this output is intangible.

- Economic growth

Economic growth could be observed either at economy wide level (gross domestic product) or at sector level. At sector level can be compared to overall economic growth or to other sector.

- Changes in industrial structure

Structure refers to transformation to existing industries, emerging of new industries or change of relative weight of each industry.

- Changes in trade (changes in input-output structure)

The previous item dealt with changes at the industrial level. This one deals with commodity level trade. Examples related to biotechnology include measures of genetically modified crops, imports and exports of biotechnology products, market penetration of biotechnology products (measured as market share).

- Changes in labour market

Adoption of biotechnology calls for different skill sets incorporating knowledge of biology and biochemistry. Progressive changes could be monitored in overall population. As well, longer term changes in employment level by sector could be monitored, especially if we are to observe a future larger demand for biomass related to adoption of biotechnology. This potential phenomenon could also alter the existing split between urban and rural populations.

Micro-economic impacts

- Business creation, growth, death, merger and, change of activity (e.g. firm moving away from petroleum to invest in biorefineries)

Biotechnology is perhaps one of the very first generic technology to emerge directly from university labs. Many firms are spin-offs from university research (Byrd, 2002). These firms are created, may survive and grow, others will disappear, move, be absorbed by another firm, not to mention the transformations happening to existing firms who may have to evolve rather than perish. This is an area of interest to those forming industrial policies interested in maximizing benefits for a country.

- Changes in price and costs structures

This is more difficult to assess since many firms will not maintain separate accounting records for products developed through the use of biotechnology (or other generic technology). However, comparisons could be made between cost structures or firms offering substitutes products where some of the firms are totally dedicated to using biotechnology where others may be producing similar products using traditional techniques. This should be done on many years to avoid distortions related to the fact that, biotechnology being an emerging technology, there might be initial development costs that may distort upward the cost structure, especially when compared to a fully developed technology incorporating years of productivity improvements.

- Impacts on competitiveness

Competitiveness relates to the ability of a firm to survive, compete and grow in a highly competitive environment. Two types of analysis or indicators development could be noted. First is establishing relationships between prices and costs structures and the ability of firms to compete as measures by market shares. Second is to establish a link between firm strategies and ability to compete.

- Changes in competitiveness conditions (niche market, mass-production using comparative advantage such as availability of feedstock)

Although very similar to the previous category, this area of indicators and analysis relates to links to be established between firms strategies and economic conditions expressed in terms of geographical locations, proximity to market, to supply sources (biomass), proximity to knowledge centers (universities and research institutes).

- Substitution of inputs (e.g. substituting diesel extracted from petroleum with bio-diesel made from feedstock or canola oil)

For generic technologies, an interesting area to monitor is the substitution specialization of inputs. It can be raw material substitution, substituting biomass for petroleum, energy sources or labour composition and organization.

The following table attempts to provide a list of potential indicators broken down by category.

Table 1. Summary of economic impact indicators

Categories	Indicators
Macro-economic impacts	
Changes in productivity via innovative products and processes	
	Productivity index by sector
Economic growth	
	Growth ratios, economy wide and by sector
	Growth ratios, biotechnogy firms vs non-biotechnology
Changes in industrial structure	
	Revenue shares, by industry, biotech vs non-biotech
	R&D shares, by industry, biotech vs non-biotech
	Firms concentration ratios in terms of revenue, employment and R&D
	Transformation, rising and decline of industries
Changes in trade (changes in input-output structure)	
	Changes in input-output patterns
	Import and export indicators, by industry and by commodity
Changes in labour market	
	Structure of labour by occupation
	Educational attainment and field of study
Micro-economic impacts	
Business creation, growth, death, merger and, change of activity	
	Number of firms creation, death, merger, acquisition
	Characteristics of firms: age, ownership (public vs non-public)
	Recording of events related to firm development: venture capital raising, IPO, licensing, alliance formation, product to market
Changes in price and costs structures	
	Prices of biotechnology product and price of subsitutes, non-biotechnology products
	Comparative cost structures of biotechnology firms vs non-biotechnology firms
Impacts on competitiveness	
	Biotechnology firm market shares and changes in market shares.
	Time serie analysis of firm growth corelated to firms characteristics
Changes in competitiveness conditions	
	Geographic location
	Proximity indicators
Substitution of inputs	
	Input structure for raw material, energy sources

Statistical requirements for the measurement of impacts

The production of suggested indicators listed previously requires many additions, changes to existing statistical collection instruments currently used and combinations of existing databases to allow for the required analytical programme. In many cases, new data is required. For others, changes in the way data are collected and to existing classifications are needed. This section describes some of the changes that may be required, following three types of changes: new surveys or changes to existing ones, changes in the classification system and, combination of existing databases.

To assess the impacts of biotechnology, and other generic technologies, specific surveys are required for the many sectors of the economy. Currently, in Canada and in many OECD countries, information is collected on biotechnology related R&D activities, many countries conduct industry specific biotechnology surveys and, few countries conducted assessment of biotechnology activities in the government sector. The higher sector is barely covered. Industry specific biotechnology surveys cover mainly the activities of firms using biotechnology for innovative purposes. Biotechnology related services are rarely covered.

A first step is to increase progressively the coverage of sectors surveyed. This will require more work to establish adapted definitions, methodologies and classifications. The OECD is already engaged in a process to adapt and establish the required definitions and methods for the government sector, to be followed by the higher education sector.

Statistics Canada explored recently a new with two surveys on bioproducts. While biotechnology surveys are based on the use of a technology, bioproducts surveys are focusing on the use of a specific input: the use of biomass for innovative purposes. There is a significant overlap between the two surveys. Biotechnology techniques may be used for the development of bioproducts but it is not a necessary condition. However, in the end, the stream of innovation emerging from biotechnology or bioproduct development still have in common the use of living organisms that is embedded in the OECD biotechnology definition. These surveys should not be considered as separate endeavours but rather as part of an effort to understand the changes at play in the economy triggered by the emergence of biotechnologies.

In attempting to isolate and analyse the emergence of biotechnology and build comparative analysis based of the wealth of information and indicators currently available for the whole economy, the main drawback of these surveys is the absence or lack of data allowing for the construction of value added indicators and productivity index. There are two main reasons for this. First, production data for the feeding of System of National Accounts indicators is already done through regular production surveys. Duplicating these efforts would impose an undue burden on respondents. It is possible to link surveys together in an attempt to build value added indicators. However, the main problem is that existing data would not be biotechnology specific, unless some of the firms are 100% dedicated to biotechnology. Second, collecting production data that is biotechnology specific assumes that respondents are able to provide such data. It is likely for the same firms that are 100% biotechnology. But where biotechnology is only part of firm’s activities, there are no indication that separate accounting records would be maintained by respondents. Still, by linking survey databases, it could be possible to perform analytical work on value added and on productivity indicators.

Building trade indicators that are specific to biotechnology would require changes in existing commodity classifications. Because of trade restrictions imposed by many countries of genetically modified crops, it would useful to find ways to create many biotechnology and bioproduct specific categories that would allow for the building of trade statistics for biotechnology. However, this is an significant endeavour since these classifications are subject to international harmonization efforts. A first step would be to perform some testing to assess the capacity to collect such information. This testing would form a basis for national and international discussions on revisions to commodity classifications.

Simultaneously or prior to changing existing surveys and classifications, important analytical work should be undertaken in an attempt to assess ways to link back to existing economic indicators. Analysis of biotechnology value addition could be attempted by linking existing biotechnology survey to other production surveys.

Conclusion

While many may recognize that biotechnology is an important transformative technology, some biotechnology applications, existing or potential, raised important and legitimate public concerns. This makes policy choices more difficult to make and to sell. Political support is uneven across capitals. Meanwhile, as exemplified by the level investment in R&D, biotechnology keeps making progress and is diffusing through the economy. This requires monitoring.

Increasing our knowledge of living mechanisms, biotechnology allows for the transformation of existing processes but, more important, for a substitution of inputs towards the use of biomass, a renewable resources, therefore with a potential to become also sustainable.

Existing surveys provides important information on the biotechnology related activities performed by the industrial sector and to some extent governments. More information is needed on the higher education sector and the service part of the industrial sector that is related to biotechnology.

The progressive switch towards more use of biomass, new product and process innovation may important substitution effects in the economy that requires to be monitored if countries wish to minimize losses and maximize benefits to their population. As often observed, large substitution effects in the economy trigger employment and capital losses in some industrial sector while we may see job creation and capital formation in others. An important motive for the monitoring of theses changes is the need to minimize the costs associated with them.

This paper discussed some areas for indicator development applicable to an emerging and transformative technology, biotechnology, but may also be considered for other generic technologies. Nanotechnology is a potential candidate. Most of the economic impact indicators proposed deals with the monitoring of substitution effects, something required to better account for gains and losses.

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